LA-UR-83-2587

CONF-830970--1

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LA-UR--83-2587

DE84 001356

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SUBMITTED TO: Invited talk at the International Symposium on Highly Excited States and Nuclear Structure to be held in Orsay, France, 9/5-8/83

EXCITATION OF GIANT RESONANCES IN PION CHARGE-EXCHANGE REACTIONS

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Abstract - The theory for excitation of electric giant isovector resonances in pion charge-exchange reactions is discussed. A comparison between the theoretical and the recent experimental results is made.

I - INTRODUCTION

With the pion factories maturing in their operations and with intense beams becoming available on a routine basis, pions have become a major tool in the study of nuclear structure and, in particular, of giant resonances in nuclei. Several years ago the observation of isoscalar giant resonances and the giant dipole in pion inelastic scattering was reported /1/. More recently, pion inelastic experiments with both π^+ and π^- projectiles have been performed at LAMPF and large asymmetries in the π^+ and π^- cross sections have been observed providing interesting information about the structure of the giant resonance excited in the process, in particular, about isospin mixing in excited nuclear states /2/.

For pion energies around the Δ_{33} resonance, the nuclear isoscalar giant resonances are excited by a factor of four stronger than the isovector ones. Therefore, mostly the isoscalar states were observed in (π,π') reactions. The pion-nucleon t-matrix has a spin-flip component proportional to $\vec{\sigma}_N \cdot (\vec{k} \times \vec{k}')$ where $\vec{k}$ and $\vec{k}'$ are the pion initial and final momenta and $\vec{\sigma}_N$ is the nucleon spin operator. In the pion nucleus optical potential this term gives rise to component which peaks around the scattering angle of $\theta = 90^o$. Utilizing this feature pion inelastic experiments were performed in which spin-flip states and in particular the so-called "stretched" states have been observed /3/.

The unique features of the pion in the study of giant resonances are probably best exploited in charge-exchange reactions $(\pi^{\pm},\pi^0)$. The pion, being an isovector, particle is most useful for the study of isovector giant resonances. The (π^+,π^0) and (π^-,π^0) reactions are kinematically similar and the availability of π^+ and π^- beams is comparable. The fact that one can simultaneously study the two charge-exchange components $\Delta T_z = -1$ and $\Delta T_z = 1$ of nuclear isovector excitation under similar conditions is at the present quite unique for the pion. Future availability of intense neutron beams may change the situation and the study of both (p,n) and (n,p) reactions could be of great interest in the study of giant resonances /4/. As we will discuss later, the measurement of both the (π^+,π^0) and (π^-,π^0) cross sections for the two charge-exchange components of the same isovector excitation may provide important information concerning the proton-neutron density distributions in nuclei /5-8/. By considering the ratios or differences of the (π^+,π^0) and (π^-,π^0) cross sections (and not necessarily the absolute cross sections) one can deduce such information.

The (π^-,π^0) reaction may in certain cases be much more advantageous than the (π^+,π^0) reaction in the study of components of an isovector giant state. The (π^-,π^0) reaction excites the $\Delta T_z = 1$ component of the isovector excitation. Because of the large Coulomb displacement energies in heavy nuclei, this component of the isovector state (in spite of the loss of symmetry energy), will be considerably lower in excitation energy than the $\Delta T_Z = -1$ component. For example, if we consider the isovector monopole state in the ^{120}Sn region, the $\Delta T_Z = 1$ component will be centered around an average energy of 22 MeV above the parent ground state while the $\Delta T_Z = -1$ component will be at an energy of about 40 MeV /7/. This lower energy for the $\Delta T_Z = 1$ component will lead to a smaller escape and spreading width for the $\Delta T_Z = 1$ component as compared with the $\Delta T_Z = -1$ one. Also, for a $\Delta T_Z = 1$ excitation the isospin of the state is limited to T + 1 while in the case of the $\Delta T_Z = -1$ component three T + 1, T, and T - 1 isospin components exist and are split by the symmetry potential. Therefore, in spite of the fact that the cross section for the $\Delta T_Z = 1$ component (due to the Pauli blocking effect) is usually smaller than for the $\Delta T_Z = -1$ one, the signal in the (π^-,π^0) reaction might be more pronounced than in the corresponding (π^+,π^0) reaction.

Other features of the pion make its use as a nuclear probe very attractive. (i) For forward scattering angles there is no spin-flip component in the pion-nucleus interaction and therefore the pion charge-exchange reaction will selectively excite electric giant resonances while the magnetic states will be suppressed. (ii) The pion-nucleon interaction around $T_\pi = 180$ MeV is dominated by the Δ_{33} resonance. The pion-nucleus interaction is strongly absorptive; therefore in a pion reaction at such energies the nuclear density at the surface is selectively probed. This feature, as we will see, makes it possible to excite some states which for less strongly absorbed particles would be excited very weakly because of the special nature of the transition density. By changing the pion energy and by moving away from the resonance one can extend the range of the nuclear density being probed. It is for these reasons that an experimental program to excite giant resonances in pion charge-exchange reactions was undertaken in recent years /8-10/ culminating in the observation of the giant isovector monopole resonance /10/.

Probably the most serious drawback in the study of pion charge-exchange reactions or of pion scattering from nuclei in general is the not yet complete theoretical understanding of the reaction mechanism and therefore the uncertainties in the calculation of pion-nucleus cross sections.

In the present work we use the DWIA framework in describing the pion-nucleus interaction. Aware of the limitation of this scheme we still believe that most of the conclusions we draw are correct because these are based on the ratios and differences in the cross sections and not necessarily on the absolute values. Our main aim is to relate the results obtained in pion reactions to nuclear structure aspects of the theory.

The entire subject of giant resonances studied in pion reactions has become too extensive to be fully reviewed in this work. We will, therefore, concentrate only on the recent results related to the excitation of giant electric resonances in pion charge-exchange reactions.

II - THE NUCLEAR STRUCTURE FRAMEWORK

The giant isovector resonances are defined with the aid of the following isovector operators:

The isovector monopole:

$$Q_\mu^{(0)} = \sum_{i=1}^{A} r_i^2 \, Y_0(\hat{r}_i)\tau_\mu(i) \qquad (1a)$$

the dipole

$$Q_\mu^{(1)} = \sum_{i=1}^{A} r_i^2 Y_1(\hat{r}_i)\tau_\mu(i) \qquad (1b)$$

and isovector quadrupole

$$Q_\mu^{(2)} = \sum_{i=1}^{A} r_i^2\ Y_2\ (\hat{r}_i)\tau_\mu(i) \qquad (1c)$$

where $\mu = \pm 1, 0$ and τ_μ is defined as

$$\tau_\mu = \begin{cases} \pm \dfrac{(\tau_x \mp i\ \tau_y)}{\sqrt{2}} & \text{for } \mu = \mp 1 \\ \tau_z & \text{for } \mu = 0 \end{cases} \qquad (2)$$

where τ_x, τ_y, τ_z are the Pauli isospin matrices. A state (or resonance) that will exhaust a sizeable part of the total strength of such operators /11,12/ we will define as a giant isovector monopole, dipole or quadrupole. In this work we are concerned mainly with these three resonances.

Let us denote the total strength for the operators $Q_\mu^{(L)}$ as

$$S_\mu^{(L)}(0) = \sum_{n_\mu} |\langle n_\mu|Q_\mu^{(L)}\ |0\rangle|^2 \qquad (3a)$$

and a linearly energy weighted total strength

$$S_\mu^{(L)}(1) = \sum_{n_\mu} E_{n_\mu} |\langle n_\mu|Q_\mu^{(L)}\ |0\rangle|^2 \qquad (3b)$$

where $|n_\mu\rangle$ and E_{n_μ} are the charge-exchange states and energies respectively, and $|0\rangle$ is the parent ground state.

The giant isovector resonances are described in the space of 1p-1h configurations. In this approach we use the charge-exchange components (i.e., $\Delta T_Z = \pm 1$) and the $\Delta T_Z = 0$ component are evaluated in the framework of the charge-exchange RPA (CE-RPA) /11,12/. The basis of the one-particle, one-hole states is constructed from the Skyrme HF solutions. The response function method is employed in the calculation of the distribution of strength. As an example, the calculated /12/ distribution of strength for the monopole in ^{120}Sn is shown in Fig. 1.

The $\Delta T_Z = \pm 1$ (or $\mu = \pm 1$) and the $\Delta T_Z = 0$ ($\mu = 0$) components are shown. One can then compute from these distributions the energy centroids /12/ for the various isospins. A result of such decomposition /12/ is shown in Fig. 2 for the monopole strength given in Fig. 1.

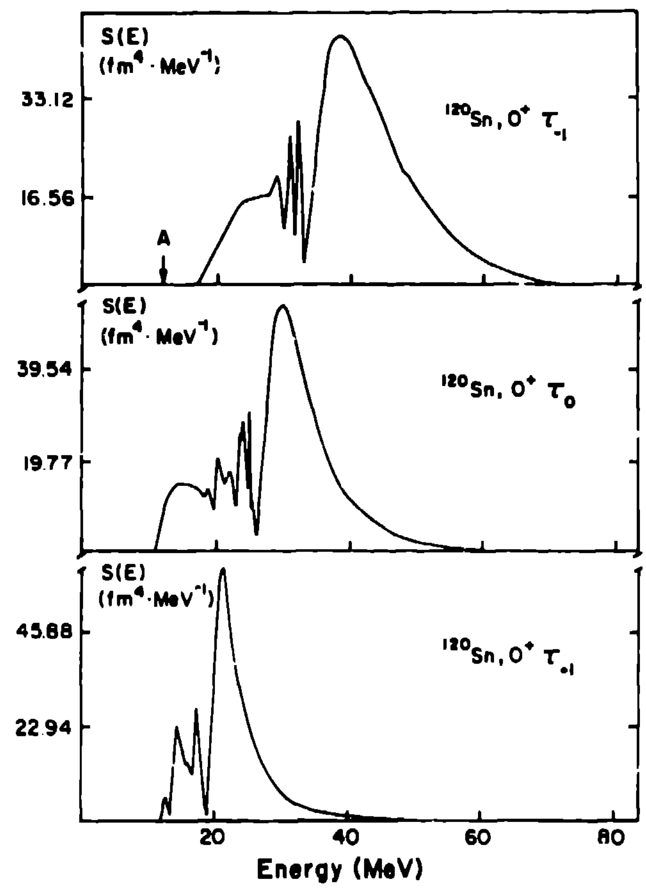


Fig. 1 - The distribution of $S_\mu^{(0)}(0)$ strength in A = 120 nuclei. The energies are given with respect to the ^{120}Sn g.s.

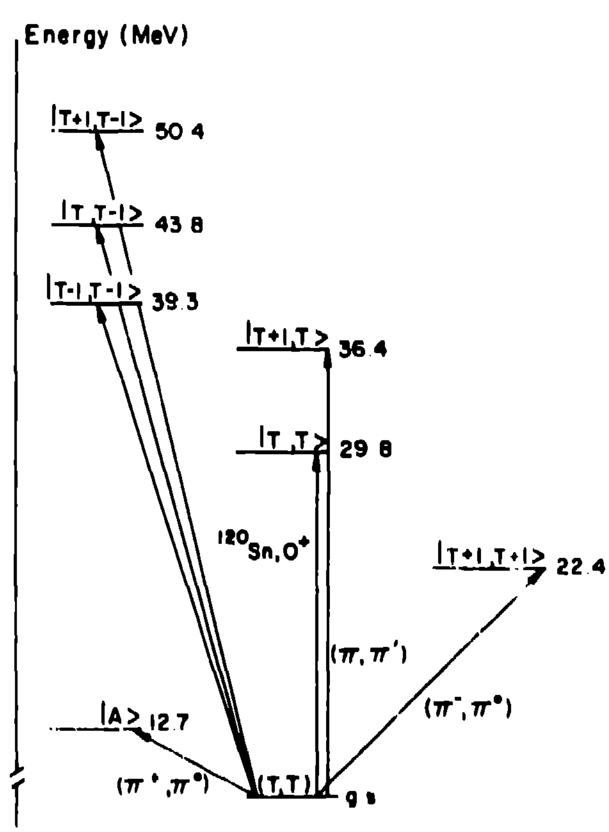


Fig. 2 - Energy centroids for the various isospin components of the isovector monopole in A = 120.

In the self-consistent CE-RPA /11-13/ non-energy weighted sum rules (NEWSR) and

The NEWSR is

$$S_{\mu}^{(L)}(0) - S_{-\mu}^{(L)}(0) = \langle\Phi_o|[Q_{\mu}^{(L)+}, Q_{\mu}^{(L)}]|\Phi_o\rangle \qquad (4a)$$

and the EWSR

$$S_{\mu}^{(L)}(1) + S_{-\mu}^{(L)}(1) = \langle\Phi_o|[Q_{\mu}^{(L)+}, [H,Q_{\mu}^{(L)}]]|\Phi_o\rangle \qquad (4b)$$

where now the states $|0\rangle$, and $|n_{\mu}\rangle$ in Eq. (3) are the ones obtained in CE-RPA. The $|\Phi_o\rangle$ is the HF ground state and H the total hamiltonian.

For the operators in Eq. (1), the right-hand side (r.h.s.) of Eq. (3a) becomes

for the monopole and quadrupole:

$$\text{right hand side} = \frac{1}{2\pi}\left[N\langle r^4\rangle_n - Z\langle r^4\rangle_p\right] \qquad (5a)$$

and for the dipole

$$\text{right hand side} = \frac{1}{2\pi}\left[N\langle r^2\rangle_n - Z\langle r^2\rangle_p\right] \qquad (5b)$$

where $\langle r^n\rangle_n$ and $\langle r^n\rangle_p$ are the neutron and proton density distribution moments evaluated using HF densities. The EWSR is more model dependent because of the two-body interactiion in H. Still one can derive for the right hand side of Eq. (4b)

for the monopole:

$$\text{right hand side of Eq. (3b)} = \frac{\hbar^2}{\pi m} A\langle r^2\rangle\left(1 + \kappa^{(0)} + \eta^{(0)}\right) \qquad (6)$$

for the dipole:

$$\text{right hand side of Eq. (3b)} = \frac{3\hbar^2}{4\pi m} A\left(1 + \kappa^{(1)} + \eta^{(1)}\right) \qquad (7)$$

and for the quadrupole

$$\text{right hand side of Eq. (3b)} = \frac{5\hbar^2}{2\pi m} A\langle r^2\rangle\left(1 + \kappa^{(2)} + \eta^{(2)}\right) \qquad (8)$$

where $\kappa^{(L)}$ and $\eta^{(L)}$ are contributions to the double commutator stemming from the two-body interaction in H. These were computed using the SIII force /11-12/. One can also derive in analogy to the strength distribution, NEWSR and EWSR for the transition densities $\rho_{n_{\mu}}(r)$ to the CE states $|n_{\mu}\rangle$.

Using the closure approximation, i.e., assuming that the entire strength is concentrated in one state, one obtaines from the sum rules the following expressions for the transition densities /4,6,7/.

For the monopole:

$$\rho_{\mu}^{(M)} = \frac{-2\frac{\hbar^2}{m}(3\rho + r\rho') - (t_1 + t_2)(3g + rg') + 2r^2(\rho_n - \rho_p)\left(V_c - \mu E_{\mu}^{(M)}\right)}{\left(E_{-1}^{(M)} + E_{1}^{(M)}\right)\sqrt{S_{\mu}^{(M)}}} \qquad (9)$$

$$+ \frac{-2\, r_{exc}^2 \rho_{exc}\left(E^{IAR} - \mu E_{-\mu}^{(M)}\right)}{\left(E_{-1}^{(M)} + E_{-1}^{(M)}\right)\sqrt{S_{\mu}^{(M)}}} \; .$$

The monopole strength is concentrated in two separated energy regions; in the isobaric analog resonance (IAR) and in the giant isovector monopole (IVM). The index M in Eq. (9) indicates that we refer to the IVM strength. The function g is

$$g(r) = 4\rho_n(r)\rho_p(r) + \frac{1}{2}\left(\rho_n(r) - \rho_p(r)\right)^2 \; . \qquad (10)$$

The Coulomb potential is denoted by V_c and t_1, t_2 are parameters of the Skyrme interaction. The excess neutron r.m.s. radius and density are denoted by r_{exc} and ρ_{exc} . The last term in the above equation results from the subtraction of the IAR strength from the total isovector monopole strength /6,7/ . In Fig. 3, the transition density calculated for ^{120}Sn is shown.

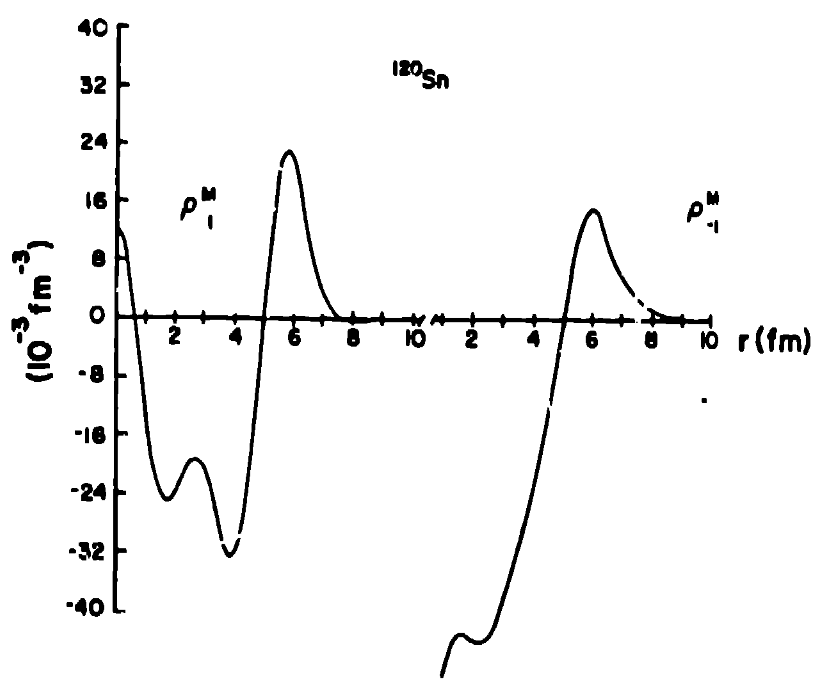


Fig. 3 - The transition densities for the two components $\mu = \pm 1$ of the monopole in ^{120}Sn are shown.

for the dipole and quadrupole of transition densities, the following expressions are derived /6,7/

$$\rho_\mu^{(1)}(r) = \frac{\frac{-\hbar^2}{m}\rho'(r) - \frac{1}{2}(t_1 + t_2)g'(r) + 2r(\rho_n(r) - \rho_p(r))(V_c - \mu E_{-\mu}^{(1)})}{\sqrt{S_\mu^{(1)}}\,(E_{-1}^{(1)} + E_1^{(1)})} \qquad (11)$$

$$\rho_\mu^{(2)}(r) = \frac{\frac{-2\hbar^2}{m} r\rho'(r) - \frac{1}{2}(t_1 + t_2)rg'(r) + 2r^2(\rho_n(r) - \rho_p(r))(V_c - \mu E_{-\mu}^{(2)})}{\sqrt{S_\mu^{(2)}}\,(E_{-1}^{(2)} + E_1^{(2)})} \qquad (12)$$

Note that in all the transition densities the first term is the same (except for the normalization) as for the corresponding isoscalar giant resonance, the second term (the one proportional to $t_1 + t_2$) is the term resulting from the exchange forces in H, and the third term is proportional to isovector part of the ground state density $\rho_n - \rho_p$.

As discussed already, the above expressions for the transition densities are derived assuming that the total strength is contained in one state (or one narrow peak).

In the framework of the response function approach one can calculate the transition density /12,14/ for each energy in the strength distribution. In such approach, the influence of the structure in the final state and in particular the continuum effects can be accounted for.

III - THE CALCULATION OF $(\pi^\pm,\pi^0)$ REACTIONS EXCITING THE GIANT RESONANCES

The transition densities derived either in the sum-rule approach or in the more detailed microscopic manner can be used in the DWIA calculations of both (π^+,π^0) and (π^-,π^0) reactions in which the isovector monopole, dipole or quadrupole is excited.

All our calculations were performed using a Kisslinger-type pion optical potential with the potential parameters determined from the pion-nucleon phase shifts. The DWPI code was used.

In Table 1 we show the results of the calculations for the J = 0^+, 1^-, and 2^+ giant resonances for several selected nuclei. The cross sections shown are for angles at which the maxima occur in the angular distributions. The angular distributions for L = 0 peak at 0° and we show the $d\sigma/d\Omega$ for $\theta = 1^\circ$. The other two resonances peak at larger angles.

In addition to calculations with the two types of transition densities we also present a calculation in which the (π^-,π^0) and (π^+,π^0) cross sections are evaluated using identical Tassie transition densities for the two $\mu = \pm 1$ components (Model 1). The difference in the (π^-,π^0) cross section is due only to the difference in the Q-values in the two reactions and the different Coulomb distortions of the π^- and π^+ in the two entrance channels. Model 2 in the table refers to calculations with the transition densities in Eqs. (9,11,12) and Model 3 refers to the calculation with the microscopic transition densities. In the case of Model 3, the cross sections were calculated peak by peak and then added up /7/. The double differential (π^-,π^0) cross section $d^2\sigma/dEd\Omega$ for the monopole in ^{90}Zr and dipole in ^{40}Ca obtained in the framework of Model 3 are shown in Figs. 4 and 5. The influence of the structure in the final state is taken into account in Model 3. This leads to an increase in the cross section as compared to Model 2.

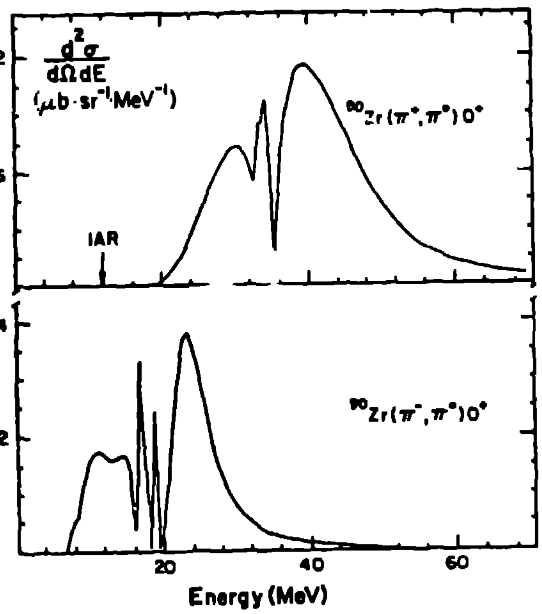
TABLE I

Nucleus	Model 1		Model 2		Model 3	
	(π^-,π^0)	(π^+,π^0)	(π^-,π^0)	(π^+,π^0)	(π^-,π^0)	(π^+,π^0)
			$J = 0^+$			
^{40}Ca	588	499	1183	846	1352	889
^{48}Ca	562	638	582	1333	672	837
^{60}Ni	634	574	865	904	966	1136
^{90}Zr	726	677	725	1088	1109	1285
^{120}Sn	780	758	470	1238	710	2094
^{208}Pb	803	752	235	1155	562	2026
			$J = 1^-$			
^{40}Ca	712	626	846	623	1154	844
^{48}Ca	612	689	227	1117	343	1490
^{60}Ni	709	657	335	762	543	1200
^{90}Zr	680	642	375	691	576	1099
^{120}Sn	689	665	60	982	166	1906
^{208}Pb	633	634	14	779	36	1454
			$J = 2^+$			
^{40}Ca	452	372	648	476	728	496
^{48}Ca	396	425	305	807	346	892
^{60}Ni	439	392	453	603	482	721
^{90}Zr	441	388	432	607	590	706
^{120}Sn	459	429	211	900	297	1334
^{208}Pb	444	391	104	781	98	905

Table 1 - Pion-charge exchange cross sections in (μb/sr) for angles at which the maxima occur in the respective angular distributions.

We now discuss some of the theoretical findings and compare these with the recent experimental pion charge-exchange results contained in Refs. 9 and 10 and the work of J. D. Bowman <u>et. al.</u> contained in these proceedings, H. W. Baer's <u>et. al.</u> contribution to <u>this</u> conference, and also in private communications with J. D. Bowman, H. Baer, and A. Erell.

The $\mu = \pm 1$ component of the dipole and the IVM were observed in a series of nuclei. The assignments of the L = 0 and L = 1 multipolarities were made by comparing the experimental angular distributions with the theoretical ones. In Figs 6 and 7 the L = 0 and L = 1 DWIA-RPA angular distributions computed for the (π^-,π^0) reaction in ^{20}Sn and ^{60}Ni are compared with the measured ones. (The theoretical curves were normalized to the data).



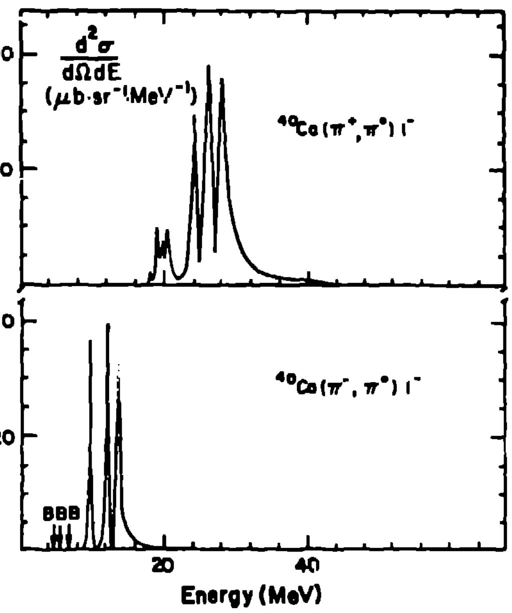
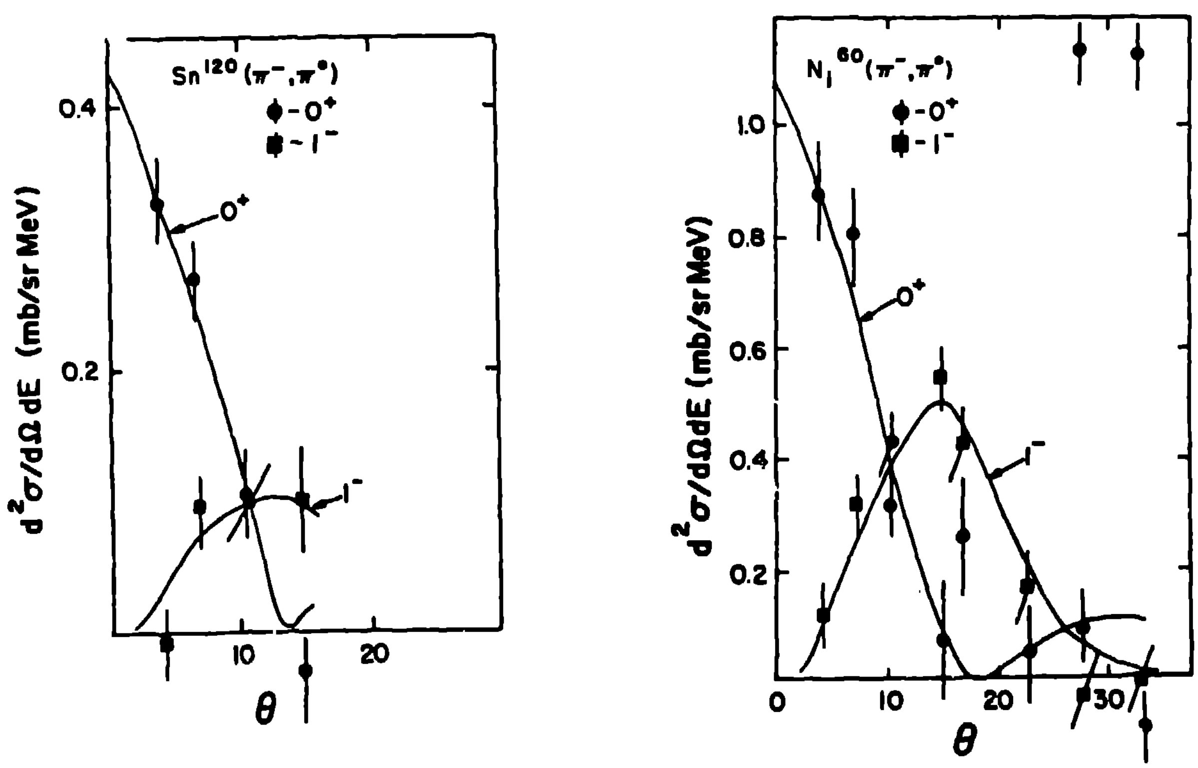


Fig. 4 - The double differential (π^-,π^0) cross-section for the J = 0^+ in ^{90}Zr for the angle corresponding to the maximum.

Fig. 5 - The double-differential (π^-,π^0) cross-section for the J = 1^- in ^{40}Ca for the angle corresponding to the maximum.



Figs. 6,7 - Experimental and theoretical angular dictributions for the (π^-,π^0) reaction in ^{120}Sn and ^{60}Ni.

The ($\pi^{\mp},\pi^0$) cross sections

The ratios of the experimental to theoretical cross sections for the dipole and monopole evaluated at the angle corresponding to the respective maxima in each angular distributions are shown in Fig. 8a.

The theoretical cross sections included in this graph are obtained within Model 3. The above ratios are of the order of 0.5. If Model 2 is used, the ratio between the experimental and theoretical cross sections is increased and in some cases is close to one.

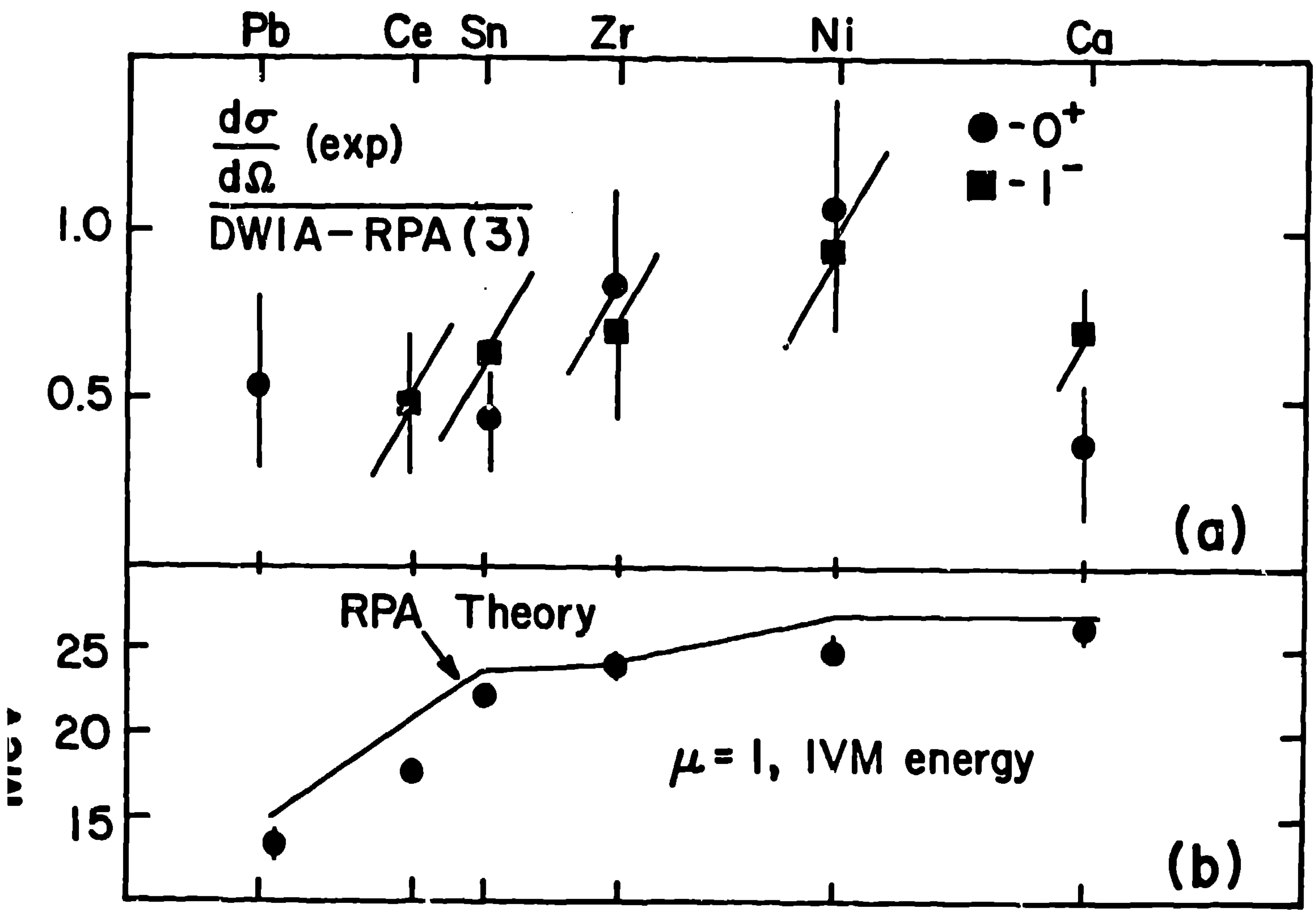


Fig. 8 - Experimental and theoretical cross sections and energies for the dipole and monopole.

The cross sections calculated in Models 2 and 3 (Table 1) show large asymmetries between the (π^-,π^0) and (π^+,π^0) cross sections. In nuclei with a large neutron excess, the (π^+,π^0) cross sections are larger than the (π^-,π^0) cross sections. This is because some of the p-h transitions which are allowed for the $\mu = -1$ mode do not exist or are forbidden because of the Pauli principle for the $\mu = 1$ mode. Therefore in $N > Z$ nuclei, the strength contained in a $\mu = -1$ excitation is larger than in the corresponding $\mu = 1$ excitations. In ^{40}Ca, we note however, that the (π^-,π^0) cross sections are larger than the (π^+,π^0) ones for all the three multipolarities $L = 0,1,2$. It was pointed out /5,6/ that this is due to the fact that in ^{40}Ca the Coulomb repulsion among protons causes the proton distribution to exceed slightly the neutron distribution at the surface and beyond it. The pions with kinetic energies around 160 MeV are strongly absorbed and therefore sensitive only to the surface region of the nucleus. If one considers the density region from about $r = 3.5$ fm and out, one finds that there are about 0.4 protons more than neutrons. In the same region, there are about two nucleons altogether; thus there is an excess of about 20% of protons over neutrons. Indeed, if one takes the ratios of the cross sections

$$\frac{\sigma^{\pi^-,\pi^0}\ (\text{Mod. }2)}{\sigma^{\pi^-,\pi^0}\ (\text{Mod. }1)} : \frac{\sigma^{\pi^+,\pi^0}\ (\text{Mod. }2)}{\sigma^{\pi^+,\pi^0}\ (\text{Mod. }1)}$$

one finds the ratio to be about 1.2 for the monopole and dipole. [We have divided, by the cross section obtained in Model 1 in order to remove the Q-value and pion-distribution effects]. The ratio $\sigma(\pi^-\pi^0)/\sigma(\pi^+,\pi^0)$ for $L = 1$ in both Models 2 and 3 is about 1.36 while the experimental ratio for these cross sections is presently determined to be about 1.3 (see J. D. Bowman et al., these proceedings, and H. W. Baer et. al., contribution to this conference). For the monopole, the calculation predicts the ratio to be about 1.5 and the experimental number is presently around 2.

As one proceeds to heavier Ca isotopes, the number of the neutrons increases and also the neutron r.m.s. radius increases so that the right-hand side of Eq. (5) is positive and one expects the $\sigma^{\pi^+,\pi^0} > \sigma^{\pi^-,\pi^0}$ for transitions to the dipole or monopole. In Fig. 9, we show the behavior of

$$\eta_L = \frac{\sigma^{\pi^+,\pi^0}\ (\text{Mod. }2)}{\sigma^{\pi^+,\pi^0}\ (\text{Mod. }1)} - \frac{\sigma^{\pi^-,\pi^0}\ (\text{Mod. }2)}{\sigma^{\pi^-,\pi^0}\ (\text{Mod. }1)} \qquad (13)$$

for the dipole ($L = 1$) and monopole ($L = 0$) transitions as functions of the number of the excess neutrons in the Ca isotopes.

It is clear from the above discussion that the measurement of the $\mu = -1$ and $\mu = 1$ components of giant isovector resonances yields useful information concerning the neutron-proton distributions in the surface region of nuclei. Charge-exchange experiments exciting the two components of the dipole and monopole with the Ca isotopes chosen as targets should be of considerable interest in view of the theoretical predictions in Fig. 9.

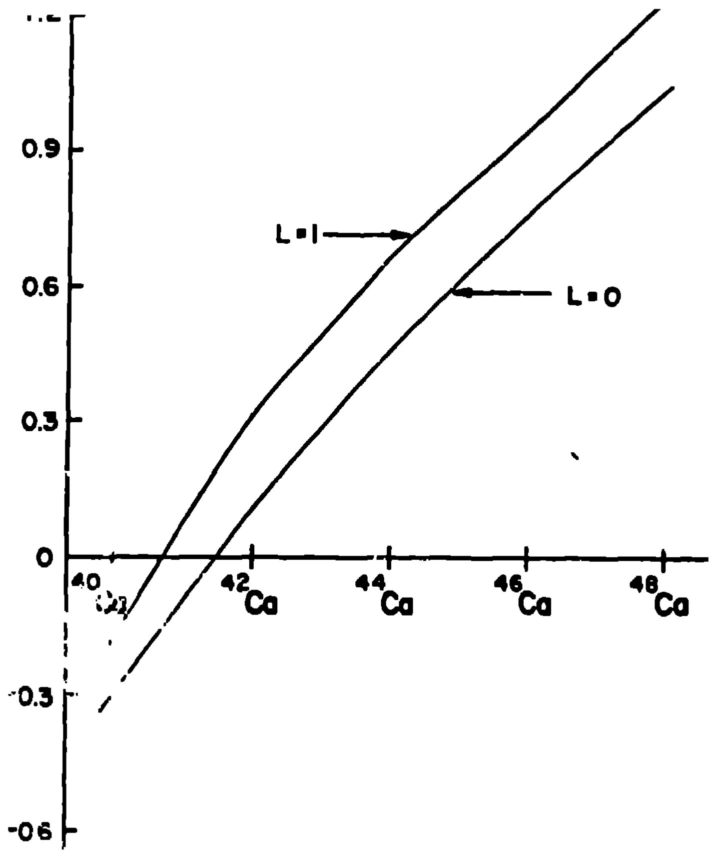


Fig. 9 - The η_L (Eq. 13) for the even Ca isotopes.

Excitation Energies and Widths

The calculated excitation energies of the charge-exchange components for the dipole are in very good agreement with the measured ones /7,11/.

In Fig. 8b, the newly measured excitation energies for the $\mu = 1$ component of the IVM as deduced from the (π^-,π^0) experiments (see J. D. Bowman's contribution) are compared with the RPA centroid energies $E_i^{(0)}$. The agreement is quite satisfactory.

The continuum RPA calculations yield only the escape widths for the giant resonances. The $\mu = 1$ components of the IVM have low excitation energies where the density of 2p-2h states is relatively low and calculations of spreading width are possible /15/. The computed spreading widths, together with the RPA escape width give total widths for the $\mu = 1$ IVM, which are in overall agreement with the experimental findings /10/ , (see J. D. Bowman's et al. contribution). The A-dependence of both the calculated and experimental width is such that the widths decrease with increasing A.

IV - SUMMARY AND OUTLOOK

The pion, as we have seen, has proven to be a useful probe in studying giant resonances in nuclei. In particular, in charge-exchange reactions in the forward direction, the pion excites selectively isovector non-spin flip states. Because of the strong absorption in the pion-nucleus optical potential states, for which a weakly absorbed particle would have had a small cross section in the forward direction (for example the monopole), are excited quite strongly with 160 MeV pions. By changing the kinetic energy of the pion one can change the depth of penetration of the pion and therefore in principle be able to probe different parts of the density.

The most advantageous feature of the pion as a probe is the ability to excite both charge-exchange components of an isovector excitation in the $(\pi^{\mp},\pi^0)$ reaction. In such cases, one can consider the ratios or differences in the cross sections to the cases, for example the [illegible] about proton-neutron distributions in the tail region of the nucleus.

The use of the (π^-,π^0) reaction and the excitation of the $\mu = 1$ component of a giant isovector resonance has been successful because of the relatively low excitation energy of this component and their narrow width.

Several problems must be resolved before the pion becomes an even more successful probe of nuclear structure. The most important objective is to have a better theoretical description of the pion-nucleus reaction mechanism and more accurate predictions of pion-nucleus cross sections.

The analysis of the pion data related to the excitation of giant resonances encounters the problem of a large background, which is subtracted using a phenomenological prescription (see the presentation of J. D. Bowman). A theoretical understanding and calculation of the background in the $(\pi^\pm,\pi^0)$ reactions will be of considerable help in analyzing and understanding of the data.

The nuclear structure calculations we presented together with the DWIA predict sizeable cross sections for the isovector quadrupole resonance. The $J = 2^+$ cross sections at maximum are, in general, about a factor of two smaller than the ones for the monopole at their maxima (See Table 1). No clear signal for the quadrupole resonance has been observed in the $(\pi^\pm,\pi^0)$ reaction. The DWIA theory predicts that the $L = 2$ angular distribution is rather slowly varying (as compared to $L = 0$ or 1) in the angular range measured in the experiments. It is possible therefore, that some amount of quadrupole strength is in fact "hidden" in the subtracted background. Still, the present analysis of the data in which the theoretical angular distributions are used puts the upper limit for the amount of quadrupole strength to be only 20-30% of the calculated NEWSR. The reason for this difficulty is not clear. It might be that the pion-nucleus description of the $L = 2$ angular distribution is inadequate or that there are some nuclear structure reasons that prevent the observation of the $J = 2^+$ mode. It is not inconceivable that the quadrupole strength is more fragmented and also more spread by the 2p-2h configuration than the other resonances considered. One should try to resolve this problem.

The outlook for pion inelastic and pion charge-exchange reactions exciting giant resonances is quite promising. New experiments that will measure the monopole and the two charge-exchange components of the dipole in many other nuclei is of considerable interest for nuclear structure studies of collective motion. As already emphasized, the measurement of the $\mu = \pm 1$ components of the dipole (and possible monopole) on such targets as the Ca or the Ni isotopes seems also promising for the study of proton-neutron distributions.

We should stress here that many of the results and conclusions concerning nuclear structure apply also to other charge-exchange reactions. In particular, (n,p) reactions complementing the (p,n) reactions should be of great help in observing isovector resonances. Also reactions with light ions such as $(^3He,t)$ /16/ and $(t,^3He)$ or $(^6Li,^6He)$ /17/ and $(^7Li,^7Be)$ /18/ will provide interesting information about the charge-exchange components of nuclear isovector excitations.

ACKNOWLEDGEMENTS

I thank H. W. Baer, J. D. Bowman, A. Erell, and Amir Klein for helpful discussions. This work was supported by the U. S. Department of Energy.

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